

Gerber Project for Lockheed Martin

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ABSTRACT

Lockheed Martin, the world's premier aerial combat vehicle manufacturer was pressed to find an eco-friendly way to package their impregnated epoxy. In the current system, the epoxy would be cut on the Gerber table to a pre-determined length and then sandwiched inside of two corrugated fiberboard sheets for storage inside of a freezer. The current process was not only labor intensive, but the corrugated fiberboard had to be disregarded after one use. In conjunction with the Cal Poly San Luis Obispo Packaging program and Melmat Incorporated, we were able to find a corrugated plastic substrate to replace the currently non-reusable fiberboard. Through a very tedious design process and multiple prototypes, we were able to construct a working prototype for Lockheed which they were able to test in a closed environment. The polypropylene material held up well after being subjected to cold and room temperature environments. The following report details the whole senior project in its entirety and summarizes how we found a solution for Lockheed Martin.

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SECTION I INTRODUCTION

Brief Company History: The Lockheed Martin Corporation was founded in 1995, when formally a defense contractor Lockheed decided to join powers with Martin Marietta. The two separate entities came together to form the most powerful and successful defense contractor to date. Lockheed prides itself on being the best when it comes to aerial combat aircrafts and the F-22 Raptor and F-35 Lightning are perfect examples. Since their merger in 1995, Lockheed Martin has continued to grow exponentially and most recently boasted over 3 billion dollars in profit in 2008(Mintz 1996). Over 95 percent of their profit comes from their defense contracts with government and they employ 146,000 employees all throughout the United States(Mintz 1996).

Problem Statement: In reading a short summary of the Lockheed Martin Corporation, you can see that they pride themselves on being industry leaders and on the cutting edge of new technology. With that in mind, we found it very interesting that they were using such a labor intensive process with such an inferior packaging substrate. There are many problems that currently pertain to the Gerber Project, but we feel the most important is the inefficiency within the whole process. The problem is that Lockheed is packaging their composite kits in corrugated sheets and storing them in a freezer. This causes the corrugated sheets to become moist and lose their mechanical properties. Once the corrugated is not able to be used again, Lockheed must then cut out a new sheet to package the kits. This is a non-value added step that is a waste of time and materials.

Packaging Process and Material: Currently, Lockheed has two to three workers that are in charge of storing, retrieving, packaging, and delivering the epoxy impreg sheets to the manufacturing floor. They must cut the corrugated fiberboard to the length and width of the epoxy impreg sheet. From there, they must label it correctly, make sure the sheets are secured within their plastic bag envelope, and then lastly must tape the edges shut on all four sides. Once all of that has been finished they must find the corresponding shelf inside of the freezer and stack it on the corresponding shelf horizontally.

Looking at this process, it is obvious that there is an excess amount of “Muda” or wasted time and effort. We believe this can all be cut down with switching to a new material that can not only be recycled, but will be pre cut to the desired sizes of the Epoxy Impreg. We haven’t been able to confirm what the sizes of these containers will be, but we assume for now that the smallest would be around 6 feet long, with the longest being around 15 feet.

Recycling: Being the industry leader that it is, Lockheed Martin is very aware of the carbon footprint and wastes present within all of their processes. In striving to become a business recognized for its “Green” or sustainable practices, this is a perfect place to start. In the current process, there is limited use of the corrugated fiberboard due to the deterioration while being dragged in and out of the freezer. The adhesives and material that make up the corrugate structure can only withstand one or two uses before the fibers lose their strength and become useless. Commonly known as cardboard, this material is recyclable but the amount of energy used in the recycling process could be greatly reduced by switching materials.

Needs: The Gerber project will benefit many of Lockheed’s employees in a positive way. For example, the solution will eliminate make it easier for the production employees on the line to pack and unpack the composite inside. It will also benefit Lockheed as a whole because it will save them money from eliminating the purchasing of corrugate fiberboard. We as students will also benefit from this project because of the experience we will get by working with other people in industry. It will teach us how to communicate and give us something good to put on our resume if we do a good job. One other company that will benefit is the corrugate plastic supplier. We have had communication with a company called Melmat, who is one of these suppliers. If they can supply Lockheed with the appropriate shapes and sizes that they need, Melmat will benefit in the business they will receive.

The new package implemented must satisfy the following needs:

Table 1- Needs Chart

Needs	Reduce Waste	Protect	Eliminate	Puncture	Labeling
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		Composite	Non-value added steps	Resistant	System
Scale 1-5	3	5	4	3	4

Reduce waste is labeled as a three because compared to the current corrugate, if the new solution eliminates even a little bit, the improvement is a success. The overall need of the package is to protect the composite from damage, so that is a five. Eliminating a non-value added step means that any activity that does not add to the value of the product is a waste. This is important because it allows Lockheed to eliminate a step in the Gerber process. The material just needs to be as puncture resistant as the current corrugated fiberboard. A labeling system is important to the process because it allows Lockheed to quickly and easily know what package is what kit.

Background or Related Work: The authors have been In the Industrial Technology program for a little over 4 years now, and have taken numerous classes that relate to the Gerber project.

Advanced packaging, Industrial Materials, and Manufacturing Processes are areas in which we feel comfortable with our level of knowledge. Polymer science is a very broad topic which encompasses wide variety of issues when dealing with plastics. But through understanding the basic chemical make-up of the common plastics used throughout industry today, we feel that we can choose a material that will present itself as a viable option for Lockheed Martin to adopt into their Gerber process. Within this report, you will find research on all the materials we are currently taking into consideration and from there it will be clear which material will give us the best chance to be successful.

Potential Solution (s): There are many possible solutions available to fix the Gerber project, but the main operative for our group is find the most cost effective and efficient solution to the problem. As we continue research materials and costs, we will eventually find an option that not fixes the problem, but hopefully leads to further advancement in sustainability throughout the manufacturing process. If we could find a material that could replace the corrugate fiberboard currently being used, we would alleviate the need for workers to waste time cutting specific sizes every day. Currently, we are leaning towards a plastic material to replace the corrugated

fiberboard currently being used. The idea of a sturdy, lightweight material is very attractive for this application. One of the best characteristics of the plastic is that once it is cut to size, it is very possible that Lockheed could increase the use per part exponentially. In terms of specific polymers, Polyethylene Terephthalate (PET), Polypropylene, and possibly some type of Acrylic monomer. An addition to these materials, there are some new technologies that could be very effective for the Gerber issue. Corrugated plastic is a new design which would keep the same idea that Lockheed Martin is currently using, but would add a more reusable aspect to the process. There is still a lot of research to be done, but we believe that plastic is the way to go. Now, the material process selection continues and will eventually lead to our group developing the first prototype.

Scope of the Project: To completely understand the scope of such a part specific project, one would have to look at the complete manufacturing process of the Lockheed Martin aerial combat vehicles. There are so many different processes which go into the assembly of these highly sophisticated and arguable most technologically advanced planes in the world. To be able to find out what we need to accomplish, we must isolate this specific process of the assembly and find a way to make it more efficient. This section of the project is reaching into uncharted waters because this is a very specific project and hasn't been attempted by anyone outside of the Lockheed Martin Company. The current solution they have to the problem is not very efficient in many different ways, yet they have settled on this solution simply because it works and essentially gets the job done. In working with them, they are very anxious to bring a new refreshed idea into the workplace, and most importantly alleviate the man hours and physical labor it takes to package and remove the material from the storage unit to the manufacturing floor. It will be important for us to research the specific process and understand the materials we are dealing with, and we must also look into the possible materials that can replace the corrugate "envelopes" that they are currently using.

SECTION II

LITERATURE REVIEW

The purpose of this project is to find a sustainable solution to the Gerber project packaging process. The literature review will cover lean solutions that have been used in the past to change a process from being wasteful to lean. It will also cover some methods of which to package composites, and some plastics that are used for this similar storage. Lean manufacturing is a process that eliminates waste while producing quality products for less money. This is accomplished by implementing tools that change the process of how the company does business.

Two professors at the Chia University in Taichung, Taiwan, leaned out the honeycomb bonding process. Honeycomb is a composite comprised of honeycomb middle with two outer walls that are impregnated with epoxy to stiffen the materials. The honeycomb is mostly air which keeps the material light. Honeycomb is a widely used material in the automotive and construction industries. Common metals are now being replaced by composite materials because of the fact that composites are less corrosive and have better anti-fatigue properties. This has greatly been accepted into the aerospace industry as well. Since the aerospace industry is starting to use composites exclusively, honeycomb producers need to lean out their production in order to get orders out faster, with better quality, and cost effectiveness.

Toyota was the originator of the lean system, and focus on 14 key principles. The 14 principles from Liker in 2004 are as follows:

1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
2. Create continuous process flow to bring problems to the surface.
3. Use “pull” systems to avoid overproduction.
4. Level out the workload (heijunka)
5. Build a culture of stopping to fix problems, to get quality right the first time.
6. Standardized tasks are the foundation for continuous improvement and employee empowerment.
7. Use visual control so no problems are hidden.

8. Use only reliable, thoroughly tested technology that serves your people and processes.
9. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others.
10. Develop exceptional people and teams who follow your company's philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve.
12. Go and see yourself to thoroughly understand the situation.
13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.
14. Become a learning organization through relentless reflection and continuous improvement.

Many car companies have gone from push system, mass production processing into lean manufacturing. "For the aerospace industry, due to its special demand for manufacturing process, change of engineering, order quantity, and cost control, lean technology can be expected to gain much more benefits if we properly design and implement lean techniques and methods" (Lui and Chiang, 2009). Lockheed Martin uses some sort of composite materials, or a combination of different composites in order to construct their jets. Honeycomb may be one of them, but it is a private matter.

The first step taken was to value stream map the procedure. This tool takes the original process of making the honeycomb, and looks at all the different materials and information flow. Value stream mapping is done by analyzing the different inputs and outputs of the process. The next step is to go Gemba (workplace) and see what is actually happening on the floor level. Then, once the whole process is understood, a value stream map can be drawn out and used to see where the value added, non-value added, and necessary non-value added work is done in the process (Lui and Chiang, 2009). Lockheed Martin is a huge facility and some people are unaware of the Gerber process. In order to fully understand it, people must go and see what the current situation is.

The second step taken was to calculate the takt time and the workload for the process. This calculation is used to know how many finished products need to come off the line in order

to keep up with demand of the customer. It is calculated by total working hours divided by the order demands (Lui and Chiang, 2009). Right now, it seems that Lockheed Martin does not know a takt time because some kits sit on the shelves in the freezer longer than others. This proves that there is not a steady takt time for the process.

Step three was 5S, Kanban, and Cellular-Layout Plan. 5S is a process of looking around a factory and basically cleaning everything up. This is used to organize all the materials, equipment, tools, trash, and people in order for the process to be less wasteful, and stand for sorting, sweeping, standardizing, simplifying, and self-discipline (Lui and Chiang, 2009). Kanban is a system that ensures that the process is a pull system and not a push system. It is a visual key that tells the process prior to make another piece, or to wait until the Kanban signals for another. This also ensures no excess inventory. The cellular-layout is used to place the machines or stations in the correct order, so that it can be passed from station to station with minimal conveyance.

Step four of the lean process was line balancing. There are five processes that need to be done to balance the line according to Lui and Chiang, and they go as follows:

- Step 1. Complete work measurement and record all data.
- Step 2. Obtain takt time and compare with cycle time. Takt time is calculated by dividing total effective working time for the period by total demand.
- Step 3. Depict a balance analysis sheet.
- Step 4. Analyze production line using takt time and cycle time to identify the location of bottleneck stations.
- Step 5. Improve the bottleneck stations by relocating or redesigning workstations. A balanced cell is preferred, where the cycle time of all operations are within 30% of one another.

According to Lui and Chiang the fifth and final step of the lean process is Heijunka. Heijunka means leveling out the workload. This is done, in four steps:

- Step 1. Break down the total volume of orders for a given planning period into scheduling intervals.
- Step 2. Define a repetitive production sequence for that scheduling interval by a heijunka calculation.
- Step 3. Dictate the model mix scheduled on a given line.

Step 4. Use kanban cards or signals for the mix of products to put that schedule into operation (Lui and Chiang 2009).

Through these five steps of implementing lean Lui and Chiang were able to achieve the following:

1. The batch size is reduced from 640 pieces to 16 pieces according to the takt time computation and the heijunka schedule.
2. The shape of material flow is changed to U-shape flow resulting from the cellular-layout design.
3. The travel distance decreases to 258 meters from 504 meters.
4. The work-in-process inventory is reduced to 424 pieces from 802 pieces.
5. The production cycle time decreases to 43 days from 117 days.
6. The fabrication time per piece is reduced to 15.31 hours from 18.13 hours.
7. The workforce decreases to 23 persons from 30 persons.
8. The process cycle efficiency increases to 4.97% from 1.99%.
9. Production cost is reduced to 214,000 NTD from 225,000 NTD.
10. The quality failure cost is reduced to 0.099% from 0.399%.
11. The throughput per run increased to 16 pieces from 8 pieces.

If the corrugated system is changed to a more sustainable packaging solution, this will take out a non-value added step in the process.

As we spoke about earlier, when building a large highly sophisticated product such as the F-22 Raptor, there are a lot of critical steps and processes that must take place. Lockheed has really thrived over the last decade by reducing the amount of waste in their manufacturing process. Although we weren't able to witness the construction of the plane first hand, it is obvious that the Gerber Project represents an integral part in the construction aircraft. The question is, why has Lockheed been using such a labor intensive and wasteful process for so long?

When most people think about the assembly and manufacturing of a vehicle, you think of a huge assembly line where a block of metal slides down a conveyor belt as workers add the essential parts needed to construct the vehicle. Henry Ford initially made this idea of "mass production" extremely popular and it was the best way to assemble vehicles for a long time. Without getting into too much detail about cars, you could imagine how boring and labor some it

would be to have to install air conditioning knobs all day long. The idea of mass production is basically breaking the production process into small trivial tasks that could be performed by just about any human being. (Raymer, 2008) The good thing about mass production is being able to alleviate the need to expensive upfront training and there are less specialized tasks that only one or two people can complete. Of the many problems that come along with mass production, low worker morale seems to be the most important. If a worker doesn't take pride in his/her job and feels like they are a replaceable pawn in a game of chess, the quality of the product being produced is in jeopardy. On mass production lines, workers really have no say so how the process works and if there is bad part of maybe something is going wrong, these workers are less likely to notice it because they are strictly concentrating on their own tasks instead of the big picture. The mistakes are then passed on to the final product where a product line manager or design engineer is left fixing a serious problem, which could have been fixed when it was of a much smaller magnitude.

In looking at Lean production, one of the most important aspects is the empowerment of the workers which gives them the ability to stop the whole process at any time if they think there could be a serious error on the production line. From there, specific tasks group look to isolate the problem and then find a solution, which will inevitably cut down on the number of bad parts being made and the post production work. Michael Roos, the director of the Massachusetts Institute of Technology (MIT) International motor vehicle program, felt these simple ideas could be applied to assembly of Aircrafts. With the help of some MIT graduate students and research that is still continuing today, they created the Lean Aircraft Initiative (LAI) which essentially adopts the 14 rules of lean manufacturing and applies them to aeronautical engineering and manufacturing.

Toyota, very successful Japanese car manufacturer, was the pilot for this new idea of Lean Manufacturing, and even today they continue to set the standard of how to cut unneeded wastes out of your business. (Cook and Graser, 2001) Yet, when applied to the assembly of planes, it is a whole different "can of worms" than trying to build a Toyota Corolla. In terms of Lockheed Martin, these planes are touted as the best fighter jets ever assembled and the

technology and time that goes into them is what separates them from the rest. The Skunk works, which is a subdivision of Lockheed Martin which specializes in the design and preservation of the most up to date technological advances in terms of aeronautics and fighter jets. Kelly Johnson, one of the major project developers at Lockheed, fell in love with the Japanese based “14 points” which were published in the book “The Machine that changed the world”. These 14 points helped get rid of a lot of waste, which in part saved time, which most importantly helped save money. The first point Lockheed adopted was the assigning an experienced well trained project manager, who would be the liaison between the workers and the President or someone else high up on the totem pole. This manager had to have full control over their project with the ability to delegate workers to different tasks to help create a quality finished product. The second and third points really focused on the almost debunking the myths that went along with Henry Ford’s ideas about mass production. These two points talk about not needing 55 people to complete 25 tasks, but instead having a small, highly motivated and team-centered work groups to complete the tasks at hand. The fifth point in sense goes back to the idea of giving the project manager full power to complete the project. Although guidance from above (upper management) is always welcome, the amount of written reports should be kept to a minimum to make sure the project manager can do their job and that he isn’t being micromanaged from someone above. From then on, the points all relate back to one another except for point 14. Point 14 talks about finding the best, most qualified person for the job and once that person is found, reward them with pay raises and not by putting them in charge of more people. This basically means that although a person maybe good at CAD design, that doesn’t necessarily mean that this person is a good leader.

Looking into a more specific situation, these points we previously covered can range anywhere from the preliminary brainstorming process, all the way to the finished product leaving the runway. The most important points the Kelly Johnson was trying to stress, was that you do not need a group of 100 people to build a plane. But what you do need a bunch of small task groups that are all governed under the same Project manager. Input from outside is always helpful and will not be taken lightly, but micromanaging really hinders the process and is counterproductive to what each task group is trying to accomplish. These ideas were all

introduced back in 1985, and although they were initially very successful, Johnson worried that his new lean idea of making planes wouldn't stand the test of time. "There is a tendency today, which I hate to see, toward design by committee - reviews and recommendations, conferences and consultations, by those not directly doing the job..." says Johnson. "...Nothing very stupid will result, but nothing brilliant either. And it's in the brilliant concept that a major advance is achieved." (Raymer, 2008)

Veering away from the ideas of Lean management and looking into some the inventory aspects, when working for the government it tough to stick to the "Laws of Lean". Lockheed's biggest customer is by far the Department of Defense often abbreviate as (DOD). In lean manufacturing, you search for the value stream and try and map out the clearest and most efficient path to complete the project. By reducing bottlenecks and lead times, a company can thrive and continue to create revenue on an annual basis. But when working with the government, it is a lot harder to forecast and create that true lean JIT (just in time) scenario. For example, the F-22 Raptor is Lockheed Martin's pride and joy and although it by far not the only aircraft being made, it is definitely the one they are most proud of. The government contracted 187 of the F-22 Raptor at a cost of about 350 million dollars each. (Hartung, 2009) The surprising fact is that none of these planes have ever been used in any U.S. conflict and all 187 sit on the runways waiting to be used. So will the government buy more? No one knows, but if we did all of sudden fall into a war, would Lockheed be able to continue manufacturing? These are all things that must be taken into consideration when working in direct correlation with the government or more specifically the DOD. The most important question Lockheed has to ask is whether keeping all the parts readily available to construct a plane that will probably not see action any time soon is cost effective for their company. Interestingly enough, this all ties back into the Gerber project and the lack of efficiency in keeping all the inventory of impregnated epoxy in corrugated envelopes. In understanding the principles of Lean and through implementing them in the design process, we are trying to build to their lean resume and really help get rid of the all the waste in the Gerber process.

Material Options: Our initial plan is to alleviate the corrugate material that Lockheed is currently using and replace it with a polymer of some sort. We feel this is the best option because it will reduce the amount of corrugate material thrown away and will replace it with a re-usable polymer. In deciding which polymer to use, we are essentially researching specific types of plastic to find which one will fit this application the best. Throughout this section we will look at some of the strengths and weakness of the different materials we may use.

Polyethylene Terephthalate: Polyethylene Terephthalate, most commonly known as PET in most common packaging applications, is one of the most popular polymers of today. Polyethylene Terephthalate's most common use today is in water bottles. In addition to its relatively low cost, PET is used because of its high strength to weight ratio and recyclability. Interestingly enough, this material is only recyclable under certain circumstance (e.g.: resin content, wall thickness) yet for our application, anything used more than once would be more environmentally friendly than the corrugate. Looking a little bit deeper into the recycling properties, the tough part about re-using this material is the amount of variables that come along with it. As we spoke about before, the amount of resin, the color additives and the natural impurities all play a vital role into whether this material can be recycled or not. During the recycling process the PET is treated with a purified terephthalic acid or dimethyl terephthalate which helps break down the plastic so it can be purified and re-used (McCrum 1997). These two agents are used in chemical recycling process where the material is broken down to its simplest form, while trying to remove all of the contaminants from the material. Another recycling process is to actually regrind the material, heat it up to a temperature of around 280 degrees Celsius (Reed 2008). From there, most contaminants can be removed, but as we talked about before this isn't always the best process because different types of PET are subject to different reactions than others.

Moving on from its recycling processes, PET is a very viable option because of its physical properties as well. During our initial visit to Palmdale, we spoke with the Supervisor of Manufacturing a specifically about the possibility of replacing the corrugate fiberboard with a plastic type material. He agreed that it would be a good possibility, but it had to possess some physical properties to ensure the material being contained would not be damaged. Naturally, PET has moderate amount of crystallinity, which really decides how strong of a material we will be

working with. Although not as rigid as some of its counterparts, PET has very good strength for how light it is. The next important aspect is will this material be able to protect the material from outside contaminants. PET has arguably the best oxygen and carbon dioxide barrier a polymer can possibly have and that is why it is the plastic of choice when dealing with food and beverages (Reed 2008). But why is that important in this application? The material is an epoxy impreg sheet that will be layered onto the actual aircraft's airframe, and this material will play vital role in the overall structural integrity of the aircraft. With all this in mind, one could imagine how important it is that this material must be preserved in its purest forms in hopes of providing the manufacturer with the best material possible. Taking all these previous facts into consideration, PET is has the ability to be copolymerized with other polymers which changes the physical and chemical make-up of the material. Copolymerizing will decrease the melting temperature of the material, therefore making it more susceptible for thermoforming and blister packaging, which could be the ideal choice for this application.

Acrylic: Polymethal Methacrylate (PM), which is more commonly known as Acrylic, is commonly used today as less fragile replacement for glass. Very similar to polycarbonate, PM is ideal because of its low cost and relatively good mechanical properties (Kutz 2002). What we envision is solid encasing similar to the standing placards you see on restaurant tables. The case would be clear and could be opened on one end to allow the material to slide inside the encasing, similar to the paper that sits between the acrylic placards on restaurant tables. This material is a possible option because it remains rigid when being carried and it wouldn't allow the epoxy impreg to bend or lose shape. The only problem with this material the weight and it is very brittle. So we will have to find out how much shock this material can withstand while under extremely cold temperatures over extended period of time.

Polypropylene: The next material we looked into using was Polypropylene. Polypropylene, often abbreviated (PP) is a thermoplastic polymer that is currently used a number of different everyday application. The most common place you would see Polypropylene is on your water or soda bottle lid. It is used in these applications because of the strength needed to contain the pressurized liquid and also to help maintain the strength of the bottle. Different from most thermoplastics, Polypropylene is highly crystalline and isotactic which is part of the reason that it

is so strong (Kutz 2002). This one of the main advantages of Polypropylene because compares to PET, it is a lot stronger and therefore more rigid of structure. Looking back to introduction, we spoke about how some of the material reaches a length of almost 15 feet. This mean that is not lifted correctly, the weight could potentially pull down one side of the epoxy impreg sheet. One emphasis the manufacturing supervisor brought to our attention was trying to keep the material as flat as possible. Any bends or folds could deem that material as not usable. Polypropylene is great for such an application because its chemical makeup allows it to be very tough, resilient polymer. When we say resilient, this means these protective sheets we would design could be used for years, rather than the one or two uses they currently get out of the corrugate paperboard.

Looking further into some of Polypropylenes physical properties, we find that it has one of the lowest densities of all the resins used in packaging. The low density along with its high compression and tensile strength make this one of the strongest lightweight materials we could use. It is important to stress the lightweight factor, because the epoxy impreg sheets are sometimes stacked 15 sheets high, which make for a very heavy object to move from storage to manufacturing floor. Similar to PET, additives such as rubbers, antioxidants and UV stabilizers all add valuable properties to Polypropylene (Twede 2005). The UV stabilizers and antioxidants are especially good because they provide a barrier form the sun while being transported and also protect the epoxy from being dried out or damaged while outside of the freezer. Copolymerizing Polypropylene turns it into a material that works extremely well with cold applications. In addition to soda bottle caps, Polypropylene is also found in pipes, containers, butt hulls, and automotive parts.

In terms of recycling, Polypropylene isn't the best do to its thermoplastic properties. When reheated to be recycled, it often times degrades losing a lot of the properties which make it a good material in the first place. But as I alluded to earlier, if manufactured correctly this material could possibly last for more than one year. So in terms of reducing waste, it would cut down on two years worth of corrugated fiber. The recycling process of plastics is still evolving as landfills continue to overflow with the products most people believe are recyclable.

Corrugated Fiberboard Envelope: As we continue research and attempt to find solutions to the Gerber issue, we feel it is important to look at the current situation and all costs find how we

could make it better if we had to use the current materials at hand. Corrugate fiberboard is commonly known as cardboard by industry standards. It consists of a fluted medium sandwiched by two flat piece of paperboard. The flute size can be adjusted to meet the needs of the object being protected and can be laid flat on top of an object or formed into a box to hold multiple items.

Lockheed Martin is currently using two flat pieces of C-flute corrugate fiberboard and taping the edges together to form a cardboard envelope. Not only is this a time consuming process, but the material is only good for one, maybe two uses if you're lucky. This is because most paperboard is design to operate at around room temperature which is 73 degrees Fahrenheit. When subjected to the freezer for long periods of time, the corrugate begins to absorb moisture which causes the material to lose whatever rigidity it had to begin with (Twede 2005). From their, the starch bases glue (which is applied between the two flat pieces of material and medium) loses its adhesive properties, rendering the remaining material somewhat useless. This doesn't help the material inside or the workers having to transport and package the material.

Stiff Layered Polymers: We have looked at many different types of plastics, but the introduction of stiff layered polymers using a nano-composites is similar to the copolymerization that we spoke about before. These composite polymers work off the idea of layering the building blocks of the polymer on top of one another which results extreme strength due to the crystallinity. "Hybrid organic-inorganic nanocomposites of polymer and clay nanoplatelets have received special attention because of the very low cost of the inorganic component, relatively simple preparation, and fairly predictable stiffening behavior when introduced into polymers" (Podsiadlo 2007). These hybrid polymers have clay like tendencies which result in strengths that aren't usually associated with plastic products. Another important part of the process is being able to write and label the packaging for the Epoxy impreg material. Because although it is the same material, it is cut to different sizes and corresponds to a different part in the manufacturing process. "Cross-linked free-standing films showed high uniformity, strength, flexibility, and remarkable transparency" (Sperling 2006). This transparency is ideal because it will allow the workers to label either the actual plastic covering or simply place a label inside on the material.

SECTION III

SOLUTIONS

When trying to assess the problem at hand with the Gerber situation, it is important to not only look at this task as an independent part of the manufacturing process, but we must also take into account all of the other tasks that coincide with this specific process. The impregnated epoxy is what makes this project difficult because of the nature of the material. The impregnated epoxy is used during the fabrication of the shell or outside body of the plane. It is ideal for this application because it is lightweight and heavy duty when layered correctly. The downfall to this material is that it has limited shelf life and needs to be kept at below freezing temperatures to maintain its physical and mechanical properties. When looking for a viable solution, we must keep in mind that Lockheed Martin is very specific about not only what types of materials they are introducing into the work environment, but also where they purchase it. FOD refers to the foreign object debris or outside elements that could potentially contaminate the materials being used to assemble the aircraft. This is a very important aspect of our solutions because in speaking with the management at Lockheed Martin, it was very clear that any material being introduced into the process would have to be screened for FOD. Although the impregnated epoxy is covered protected by its primary package, which is a plastic bag, if contaminated it would waste a lot of money. Another important factor we must think about is the material we buy meets the standards of Lockheed's military contracts. As we have alluded to in previous sections, Lockheed's main customer is the Department of the Defense. The DOD has a Military Specifications that it requires its vendors to use, and depending on which company and material we choose to use, we must make sure there will not jeopardize any of their customers wants or needs.

Material Selection:

Acrylic: Polymethyl Methacrylate (PM), which is more commonly known as Acrylic, is commonly used today as less fragile replacement for glass. Very similar to polycarbonate, PM is ideal because of its low cost and relatively good mechanical properties (Kutz 2002). What we envision is solid encasing similar to the standing placards you see on restaurant tables. The case would be clear and could be opened on one end to allow the material to slide inside the encasing,

similar to the paper that sits between the acrylic placards on restaurant tables. This material is a possible option because it remains rigid when being carried and it wouldn't allow the epoxy impreg to bend or lose shape. The only problem with this material the weight and it is very brittle. So we will have to find out how much shock this material can withstand while under extremely cold temperatures over extended period of time.

Polypropylene: The next material we looked into using was Polypropylene. Polypropylene, often abbreviated (PP) is a thermoplastic polymer that is currently used a number of different everyday application. The most common place you would see Polypropylene is on your water or soda bottle lid. It is used in these applications because of the strength needed to contain the pressurized liquid and also to help maintain the strength of the bottle. Different from most thermoplastics, Polypropylene is highly crystalline and isotactic which is part of the reason that it is so strong (Kutz 2002). This one of the main advantages of Polypropylene because compares to PET, it is a lot stronger and therefore more rigid of structure. Looking back to introduction, we spoke about how some of the material reaches a length of almost 15 feet. This mean that is not lifted correctly, the weight could potentially pull down one side of the epoxy impreg sheet. One emphasis the manufacturing supervisor brought to our attention was trying to keep the material as flat as possible. Any bends or folds could deem that material as not usable. Polypropylene is great for such an application because its chemical makeup allows it to be very tough, resilient polymer. When we say resilient, this means these protective sheets we would design could be used for years, rather than the one or two uses they currently get out of the corrugate paperboard.

Looking further into some of Polypropylenes physical properties, we find that it has one of the lowest densities of all the resins used in packaging. The low density along with its high compression and tensile strength make this one of the strongest lightweight materials we could use. It is important to stress the lightweight factor, because the epoxy impreg sheets are sometimes stacked 15 sheets high, which make for a very heavy object to move from storage to manufacturing floor. Similar to PET, additives such as rubbers, antioxidants and UV stabilizers all add valuable properties to Polypropylene (Twede 2005). The UV stabilizers and antioxidants are especially good because they provide a barrier form the sun while being transported and also protect the epoxy from being dried out or damaged while outside of the freezer. Copolymerizing

Polypropylene turns it into a material that works extremely well with cold applications. In addition to soda bottle caps, Polypropylene is also found in pipes, containers, butt hulls, and automotive parts.

In terms of recycling, Polypropylene isn't the best due to its thermoplastic properties. When reheated to be recycled, it often times degrades losing a lot of the properties which make it a good material in the first place. But as I alluded to earlier, if manufactured correctly this material could possibly last for more than one year. So in terms of reducing waste, it would cut down on two years worth of corrugated fiber. The recycling process of plastics is still evolving as landfills continue to overflow with the products most people believe are recyclable.

Corrugated Plastic: Corrugated plastic is a revolutionary design that is gaining a lot of followers mainly because of its good mechanical properties and its ability to be re-used. Commonly used as slip sheets within large pallets, corrugated plastic, also known as Coroplast or Coroflute, is an ideal choice because it takes the properties of corrugated fiberboard and makes exponentially increase rigidity and overall strength. Unlike its paperboard counterpart, corrugated plastic is a lot sturdier and can be used multiple times depending on the application. In terms of FOD, this is a viable option because it can be wiped down with your common rubbing alcohol after each use to maintain a contaminant free environment. We also believe that the plastic covering on the material (polypropylene bags), should adhere well to the plastic and ensure that the impregnated epoxy will not slide around inside of the box. Corrugated plastic can be used in the same unique applications as any regular fiberboard sheet, and we look to develop a collapsible box to replace the current material being used in the Gerber process.

Package Designs:

We envision a double walled corrugated plastic box that the impregnated epoxy can be held inside of. The box will stand up on edge and then be collapsed for stacking purposes while inside of the freezer. The double wall thickness will allow the workers to remove the sheets from the freezer shelf with a lot more ease. The longer sheets (12-15 feet) will still tend to bow in the middle, but it will be a lot less than the previous material. The shorter sheets (6-9 feet) should adapt well to the new strength of the material.

There are two designs that were cut on the Kongsburg table and prototyped for Lockheed. Design 1 of the two solutions was a design that used interlocking tabs to seal the package and not have to use any other outside processes. The design would be different for each different size length of the package. The fifteen foot long sheets would have three interlocking tabs, while the shorter sheets would only need one or two interlocking tabs. The concept was modeled off of the gum containers that use interlocking tabs to seal the gum from coming out of the package. See Figure 3- Orthographic #1 below.

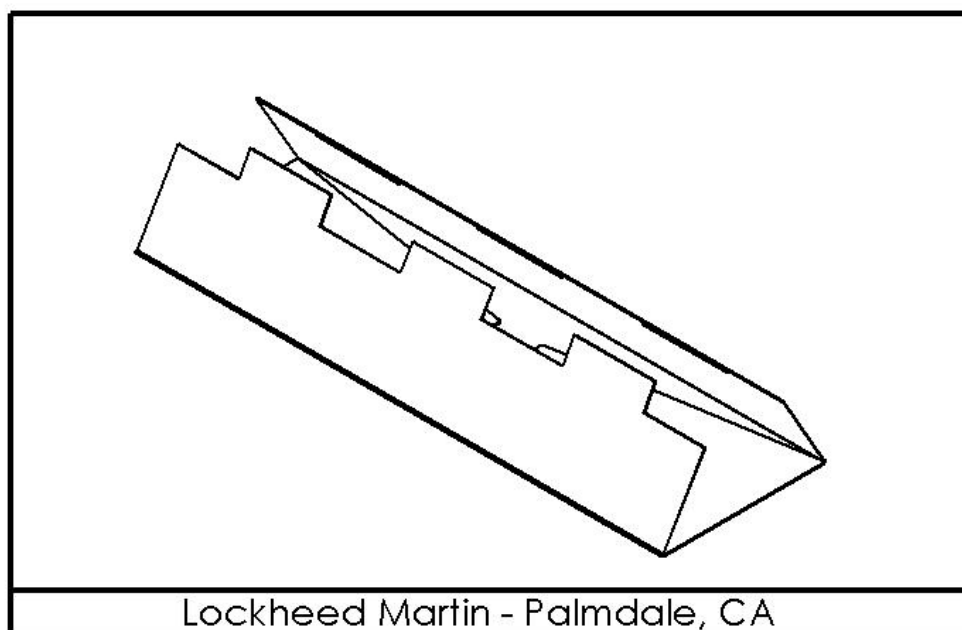
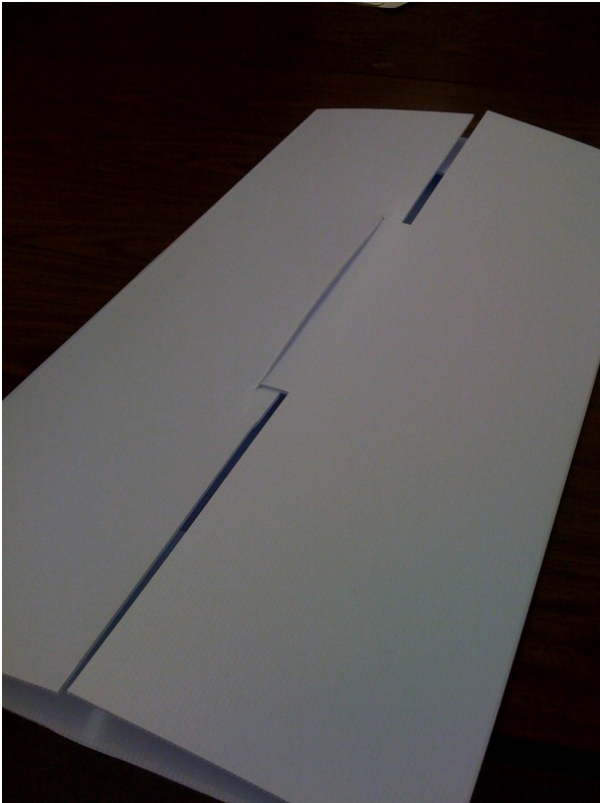


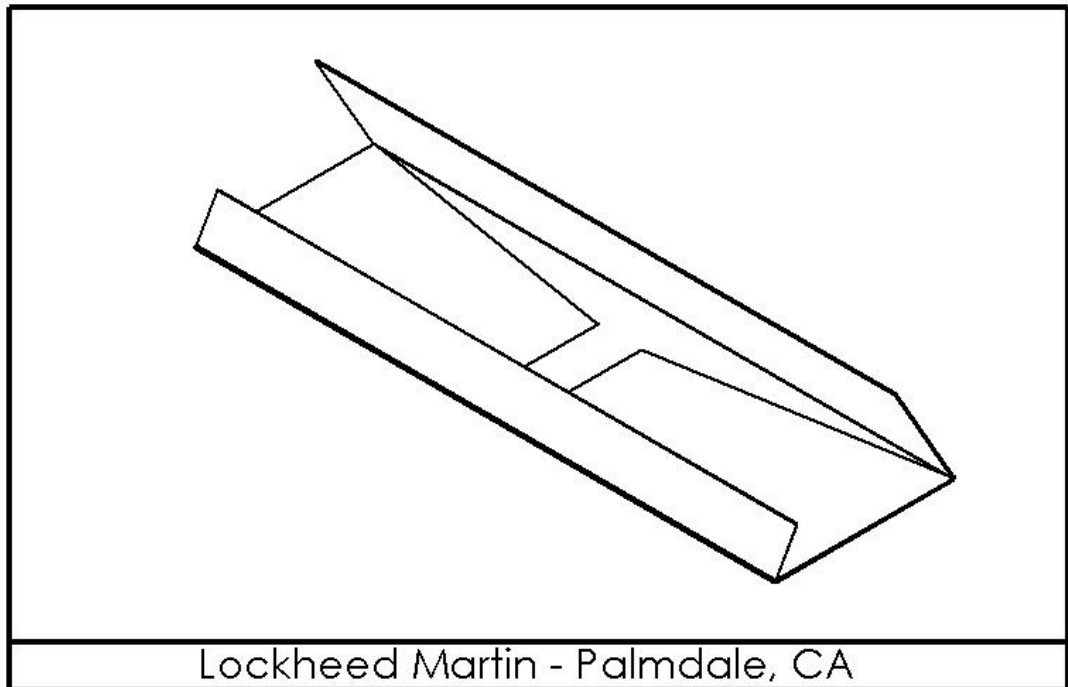
Figure 1-Design #1 Photo



Design #2 was made a simpler design but incorporated outside materials to seal it. This design has two flaps, one of the flaps folds completely over the package, and the second flap is only eight inches to ensure there is an overlap. The extra material used is Velcro. The Velcro is placed on both the large flap cover and the small flap. This ensures that the package is sealed tight and does not open up during transportation. This is the design that Lockheed ended up choosing.

Figure 4- Orthographic

#2



Variables: The main variables for the corrugated plastic will be the overall structure of the plastic boxes. The biggest variable is how long each box will hold up after continual use. The freezer will not have the same affect on the corrugated plastic as it does on the corrugated fiberboard, but the constant introduction of warm to cold environments may eventually take its toll on the collapsible boxes. We would like to know how long each box will be able to last. Because we plan to order sheets in sizes that meet the standard impreg sheet size, we must make sure that sheets fit within the specified range of the products we propose to buy. Basically, we have an arbitrary number of 6, 9, and 15 feet sheets. But if they for some reason need to cut a 5 foot piece of impregnated epoxy, will our box be able to protect it en route to the production floor. Another variable of the corrugated plastic is the perforation folds. These folds may end up breaking after being used 25 plus times, which would cause some concern as to whether or not it is financially worth it to use this material.

Removable shelving would be very costly and difficult to design. This would also take a lot of time and money to store the composites somewhere else while the freezer was being renovated. This would allow Lockheed to easily store the composites and label each drawer according to the contents. Acrylic had some good properties, but was not a feasible solution. The clear property of acrylic was a positive because the workers could directly see what was inside the sleeve. However, The fact that acrylic weighs so much more than corrugate plastic or corrugate fiberboard eliminated it from being a solution. As is, it only takes two employees to carry the biggest kit sizes of 15 feet. The acrylic would add so much weight that Lockheed might have to add an employee to the process just to carry it out. This causes more of a waste than a solution.

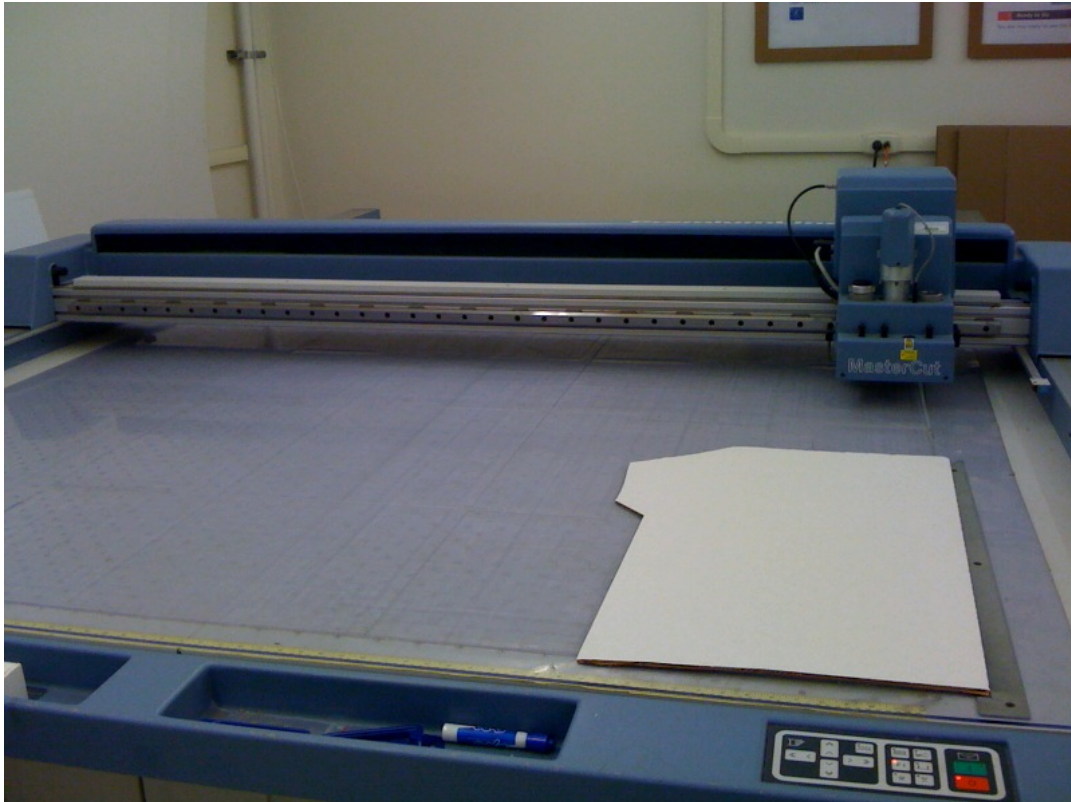
Material Handling

Removable Shelving: This is a solution that would be the most expensive of all the solutions, but may prove to be the most effective. This new set of shelving will have drawers that can be removed. These drawers could be made of anything from aluminum or some sort metal and would weigh more than the plastic solutions, but would prove to be more sustainable and durable.

The transportation to and from the freezer is a major variable because the current car they had was no longer than 10 feet long. This presents a problem because the more bending the material does prior to being applied; it causes imperfections on the surface and makes these pieces not unusable. They currently have a makeshift extension off the back of the cart which allows them to transport impreg sheets over 10 feet long. But this cannot be a permanent fix, and they are aware of that. The management at Lockheed insists that they are in the process of getting a new means of transportation for the sheets, but we feel if its main use will be to transport sheets of impregnated epoxy, then it should be designed to fit the needs of the Gerber process. This is such an important process because no matter what material we decided to store the impreg in, if we cannot ensure that it will be transported safely, then it all of the prior planning is moot.

To make our prototype we used Artios CAD and the Kongsburg table to cut out accurate and specific corrugated envelopes. With this software, it allowed for quick changeovers from one design to another. Slight changes were made from the first prototype to the last one. The first prototype is a self-containing envelope with four folding sides. The long sides that fold together meet in the middle and have a slit in which an overlap keeps them together. The second design added a height the sides of the envelope making sure that no matter how thick the composite is inside it, the sides can be adjusted to that specific thickness. Through the feedback received from Lockheed, we then made a prototype with a top flap that folds all the way across the to the opposite side, making it so that there is no seam in the middle. This prototype uses Velcro to keep the envelope closed. The original design was also modified a little to get both a self-containing prototype to Lockheed and one that has a slight after production modification (that being the Velcro).

Figure 2-Kongburg:



Lastly, the biggest variable is how much of the material will we be storing. There are a significant amount of shelves within freezer, but we were not initially able to get a solid count of much impregnated epoxy they are storing at one time.

SECTION IV

RESULTS AND DISCUSSION

The main objective of this senior project was to assess the current packaging situation at Lockheed Martin's Palmdale location. Being the successful government contracted company that they are, often times small projects such as packaging of the manufacturing materials can be lost in the shuffle. The composite materials that are used in this process present a problem that they need to be securely protected and kept at freezing temperatures until they are brought to the manufacturing floor. The problem lies in the labor it takes to cut and package each sheet of impregnated epoxy. In addition to that, the corrugated fiberboard being used is not recyclable and is becoming a serious waste as companies like Lockheed Martin push to meet environmentally friendly standards. With all this in mind, we were pressed to find solutions to a very specific process while remaining inside the scope of our senior project. With the guidance of our project advisor, we decided to present three different ideas. The first two would basically keep the current system intact, but replace the materials being used to a more re-usable option. The third and final option was a design Andrew and myself came up with that would basically allow Lockheed to renovate their freezer space to maximize the area and get the best results for this process. Although all three were viable options, the latter was a little more outside of the scope our project and would take a significant amount of time to coordinate. In this results section, we will look over these options and weigh them out to see which option truly meets the specifications we set out to meet at the beginning of the project.

Material Selection

Our first material was an acrylic encasement which would protect the material and still allow it to be stored inside the shelves of the freezer. The original idea to use acrylic was strictly

based off of the clear glass finish look and the overall strength of the material. Acrylic is optimal in many applications because it resembles glass. In terms of the aesthetics of the material, yet it isn't as brittle and can be used almost an unlimited amount of times. The design was a four wall based bottom with similar top that would have a tolerance so it could fit snug on top of the bottom of the case. The key advantage of this design was ultimate rigidity, which was one of the key points of emphasis for Lockheed Martin. Some of the sheets reach lengths of 15 feet and the current corrugate fiberboard would bow in the middle. This bowing can destroy the impregnated epoxy to the point where it cannot be used. Another advantage is the acrylic impermeable which will be helpful when being removed in and out of the freezer on a day to day basis. The ability to write on the casing would also be helpful in labeling the sheets and which project they correspond to. One of the problems we ran into with this idea was the feasibility of a wide scale production of our design. We felt this design would basically mean that they would have to ship and store a 15 foot acrylic case which can be very heavy. There would be no way to remove the cases safely while being stacked in the freezer. Another disadvantage to this material is that it is relatively expensive compared to other polymers, and it isn't really easily recyclable. In terms of meeting our initial requirements and specification, the acrylic casing was a good idea but it introduced too many other variables into the equation.

Overall Rating: 3

Corrugated plastic is one of the most intriguing options we have found through our research. The corrugated plastic is a viable option because it allows Lockheed to keep a majority of the process intact, but simply switches the material that they are using. As we have spoken about, the corrugated plastic is made up of a Polypropylene polymer which is ideal for this application. Unlike Polyethylene Terephthalate (PET) which is commonly used water bottles, the physical properties alone help distinguish Polypropylene as the perfect polymer for this job. The main idea in using a corrugated plastic instead of a corrugated fiberboard is the extended amount of use we can get from this material. The impregnated epoxy is stored in freezing temperatures and then moved outside in open air conditions. From there it may sit in the sun for upwards of 30 minutes while the rest of the products are loaded on the truck. Next, the material, packaging and all is driven to the manufacturing floor and then opened and used. The current situation calls

for disposal of the packaging which inevitably leads to another package being made. We envision that this process remains the same all the way up to the disposal of the packaging. Our corrugated plastic box design resembles an oversized envelope with a tab to secure the material inside. Ideally, we would contact our vendor and send him our designs and they would be shipped to Lockheed where they could fold and assemble the packages themselves. We imagine these packages can be used upwards of 25 times. And that in itself not only saves a lot of money, but it also last wasteful. The biggest advantage of this material is that not only is it recyclable but it gives Lockheed so many options in terms of packaging design. We initially set out to ensure that the material would be safe inside of the package and that it would decrease the amount of bowing in the middle of the longer epoxy sheets. There are so many options in terms of thickness, design features, and color coding each material.

The initial prototypes we made for our visit down to Palmdale location were very popular amongst the manufacturing staff. We got a lot of good feedback about design and sizing, which helped us move forward in the design stages. The color coding option and overall structure of the boxes were most popular. We feel this is the most viable option in terms of availability and feasible implementation. The only disadvantages would be the cutting and assembly processes. These could be somewhat time consuming initially, but in comparison the current situation we feel it will still be possible. The last and possibly most important problem we ran into with this solution is the shipping of the materials to the Palmdale location. Our contacts ensured us the shipping wouldn't be an issue, but we just have to make sure our 15 foot boxes will fit inside of 18 wheeler.

Overall Rating: 5

Our last and definitely most complex solution is scenario in which we would renovate the entire freezer room. The freezer is currently stocked with shelves and that almost reach the ceiling. Our idea would be to basically turn these shelves into a large drawer system where you could slide the cases in and out. I honestly believe if we had the time and money to design something like this, it would really alleviate the need for any wasted items and the shelf drawers could each be designed specifically to meet the specifications needed to protect this material. We were thinking of playing off of the first solution and using an acrylic material for the shelves, simply so you

could see inside of the shelves while they are mounted. The main disadvantage of this idea is the time and money it would take to implement this design. They would need to find a place to store all of the epoxy sheets while the renovation took place and that could be costly in itself. Also we will it would be very hard to remove a drawer from the top of the shelf without risking injuries of the workers. The weight of the drawer filled with impregnated epoxy would be upwards of 100 lbs. So with all this in mind, it seems like this idea is outside of the scope of our project but with the correct timing and design, it could be an option in the future for Lockheed Martin.

Overall rating: 2.5

Package Designs

As stated in the solution section, our Design #1 was made to eliminate any extra steps on the production of the package. Once the corrugated plastic is cut into its shape, the package can immediately be used and seal itself. The engineers likes the idea of the design, but said that once the package was on the floor it would be too difficult for one employee to seal the package. The wanted a more simple seal design. Design #2 was made just how the engineers wanted it. It has a full overlapping top flap that had Velcro to seal the flap down and secure the package from opening during handling. This design was liked by all the engineers and employees at Lockheed. The labeling system is the same for both designs; however, since Design #2 has a completely flat face on the top, it was easier to place the labeling system on it because it could be placed anywhere. Lockheed liked this along with the fact that the Velcro secured the package much stronger than just a tuck tab system.

Table 2- Design Comparison

Needs Scale 1-5	Reduce Waste	Protect Composite	Eliminate Non-value added steps	Puncture Resistant	Labeling System	Ease of Sealing
Design #1	5	5	4	5	4	3
Design #2	5	5	4	5	5	5

SECTION V

CONCLUSION

Throughout this project we have been ran into a lot of different problems while trying to find a solution for Lockheed Martin. Our project was unique in a couple different ways which made it intriguing to begin with, yet also difficult to complete. The first problem was working with an outside company such as Lockheed Martin. The opportunity to make a difference by designing packaging for some of the most technologically advanced aircrafts ever made is definitely an honor. But at the same time, the standard and quality of work must be raised to the level that Lockheed Martin has grown to expect. So our initial ideas were quickly nixed because we had to understand the company we were working with. The designs we are making could possibly become part of 65 billion dollar government contract, enough said. We need to find something that would actually help the company, while trying to remain inside of the scope of our senior project. After our first trip down to Palmdale, it would understatement to say that we were a little overwhelmed into what we had gotten ourselves into. But through the guidance of Anne Wolfe and Lauren Roberts, we found a way to communicate and get solid information about the process we would be working with. We got to take a thorough tour of not only the processes we would be dealing with, but also the rest of the Palmdale location. Not only did this give an idea of what we would be working with in terms of materials and locations, but it also gave a view of the big picture and how our small but important Gerber process plays a vital role.

After our meeting, we decided to start brainstorming possible ideas to how we could fix the current situation. It was almost laughable to see that such a technologically advanced company was using such an antiquated and labor intensive process on a day to day basis. Yet we soon realized that there are various limitations to the outside materials that can be introduced into the manufacturing process. And with that in mind, they tend to have a “if it’s not broken, don’t fix it” mentality about things. Andrew and I took this into consideration when thinking about the possible solutions to the problem. As we spoke about in previous sections, outside of a senior project, there are so many different ways to package and preserve the impregnated epoxy. But in this situation, we wanted to stick to basics of our packaging knowledge and present them with a

option that they would really find themselves using. Our initial designs of acrylic encasements were good, but the possibility of making these didn't seem realistic to us. The next progression led us to a corrugated plastic design which was right up our alley. It was relatively cheap, easy to use and we were able to get samples for prototyping in less than week. From there we began drawing designs on ArtiosCad which we would eventually send over to the Kongsberg table for cutting. Our first couple prototypes were using standard corrugated fiberboard, so we wouldn't compromise the limited amount of sample material we had. After assembling a couple of the first prototypes we decided to move on to the actual corrugated plastic. One of the first problems we ran into was the ability for the Kongsberg blade to cut through the material. What found was that we had to cut against the flute direction to get the results we needed, because the strength of the plastic wasn't allowing us to bend. We flipped the plastic in a different direction and tried it again which worked a lot better.

It was through a real trial and error process that we were able to design a real collapsible box that would really work. The truth is the assembly of the box isn't as easy it seems when you are using a different material than normal. But this also means that with the right cuts, folds, and creases, the box will have more stability than any other corrugated material.

After meeting with Lockheed for the final time, we were able to collect a lot of valuable information from the staff working on the Gerber Process. They really liked the design of the prototypes we gave them, but they also had constructive criticism about the ease and simplicity. They didn't like the insertion of the tabs on top of the package because in larger scale with a stiffer material, it would be extremely hard to insert the tabs. In terms of the actual material, they found that it held up very well after two weeks in the product cycle. The prototype was filled with epoxy and taken in and out of the freezer a total of 6 times. The staff was very impressed with the durability of the structure and the fact they would be able to re-use the product. The final prototype they chose to use was surprisingly our most simple design. In addition to what we gave them, they added some standard adhesive Velcro straps to the sides of the package. These Velcro straps give added protection and the much needed downward force on the flaps. This design can be found as Design #2 and as you can see it is an extremely basic design, which is

good for Lockheed because they can tweak the measurements or add parts to the current package with little to no work.

In conclusion, we found that our designs were received very well by the staff because it wasn't something that forced them to change all the current protocols they were using. In speaking with one specific worker on the Gerber Process, he estimated that we cut down the amount of wasted material by 95% and minimized process time from 15 minutes to 5 minutes. These are huge numbers because they truly quantify the work that we have put into this project. We initially set out to find and present Lockheed with a feasible solution to their problem, and with the help of Melmat and our faculty advisors, we were able to do that.

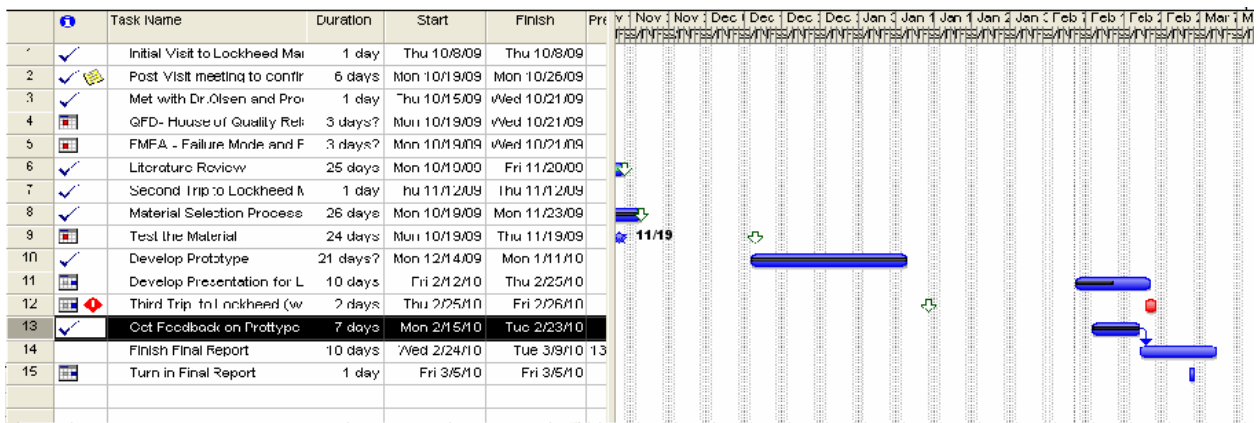
SECTION VI

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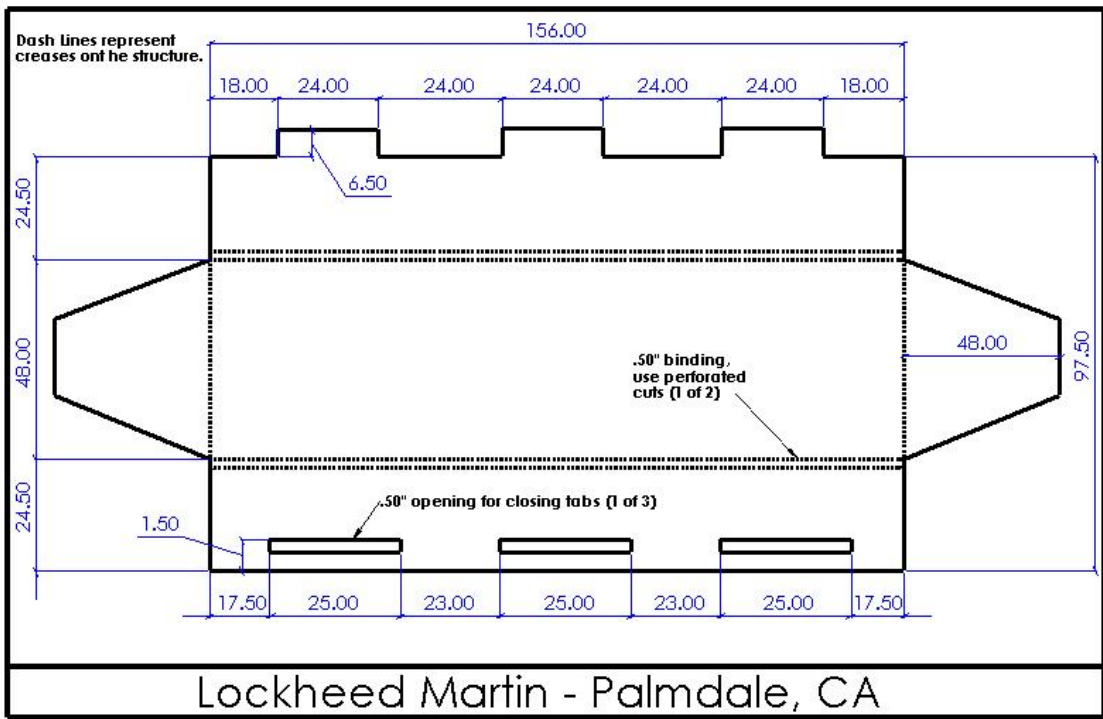
APPENDIX

A. GANTT CHART



B. DRAWINGS

Design #1 Drawing



Design #2 Drawing

